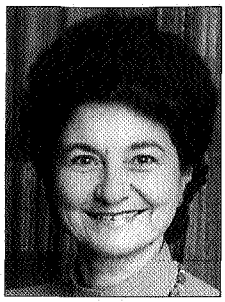

Research to optimise human performance

Margaret Bullock

The need for greater understanding of the factors which limit human movement and functional capacity and for determining effective methods for ensuring optimum performance has led to a wide range of related research studies. This paper draws on some of the research projects pursued or supervised by the author, to show the knowledge gained in aspects of movement capacity, muscle function and the influence of sensory motor deficits on movement and function. The inter-relationship of the many factors influencing functional capacity emphasise the need to think broadly in research. Studies of effectiveness of physiotherapy and collection of data for ergonomic workplace design highlight the importance of both prevention and therapeutic care and demonstrate the contributions which physiotherapists can make through research to optimise human performance.

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The importance of pursuing research in physiotherapy has been recognised for many years and is espoused increasingly today. Although physiotherapy expertise revolves around the analysis of normal and abnormal movement, the scope of physiotherapy practice is broad, covering both restorative and preventative roles, and many opportunities for research exist (Bullock 1976). The choice of research area for a physiotherapist may depend on a number of factors, including the profession's priorities for research, availability of resources or personal preference. However, where the researcher carries a responsibility for being a catalyst to research, and for establishing a range of research endeavours within a University Department of Physiotherapy, they must be prepared to diversify their interests and explore a number of different fields, often concurrently. Such was the case for this author who, after pursuing individual interests and commissioned projects, was charged by The University of Queensland with providing leadership in a range of research areas relevant to physiotherapy, encouraging higher degree enrolment, and nurturing beginning researchers. Because of this, the author has been involved in a variety of research topics, and has supervised more than 80 higher degree research theses.

Among the broad range of fundamental, applied and clinical research topics pursued by the author has been a concern to enhance human performance. As Figure 1 illustrates, complex inter-relationships exist between the aspects of human performance which influence functional capacity. Features which demonstrate the function of a muscle in individual and co-ordinated activity affect a person's capacity to move freely and safely through space, applying forces appropriate to the activity. The factors associated with muscle function, movement capacity, force capability and space requirements are inter-related and, separately and collectively, influence static and dynamic posture, while central to many of these expressions of function is sensory motor ability. Optimisation of human performance can be achieved by a combination of rehabilitation and therapeutic care, and ergonomic design and prevention. It is on each of these aspects that the author's research has dwelt and Figure 1 is offered to illustrate the sphere of research activity pursued by the author and supervised students in areas concerned with optimisation of human performance. This paper describes only some of those projects.

Ergonomic design to optimise functional capacity in the workplace

Movement is the essence of life and the study of the elements which combine to produce movement is important to the health of all individuals. However, it is important to realise the extent of the body's capacity for movement and the limitations on demands which must be made in recognition of the

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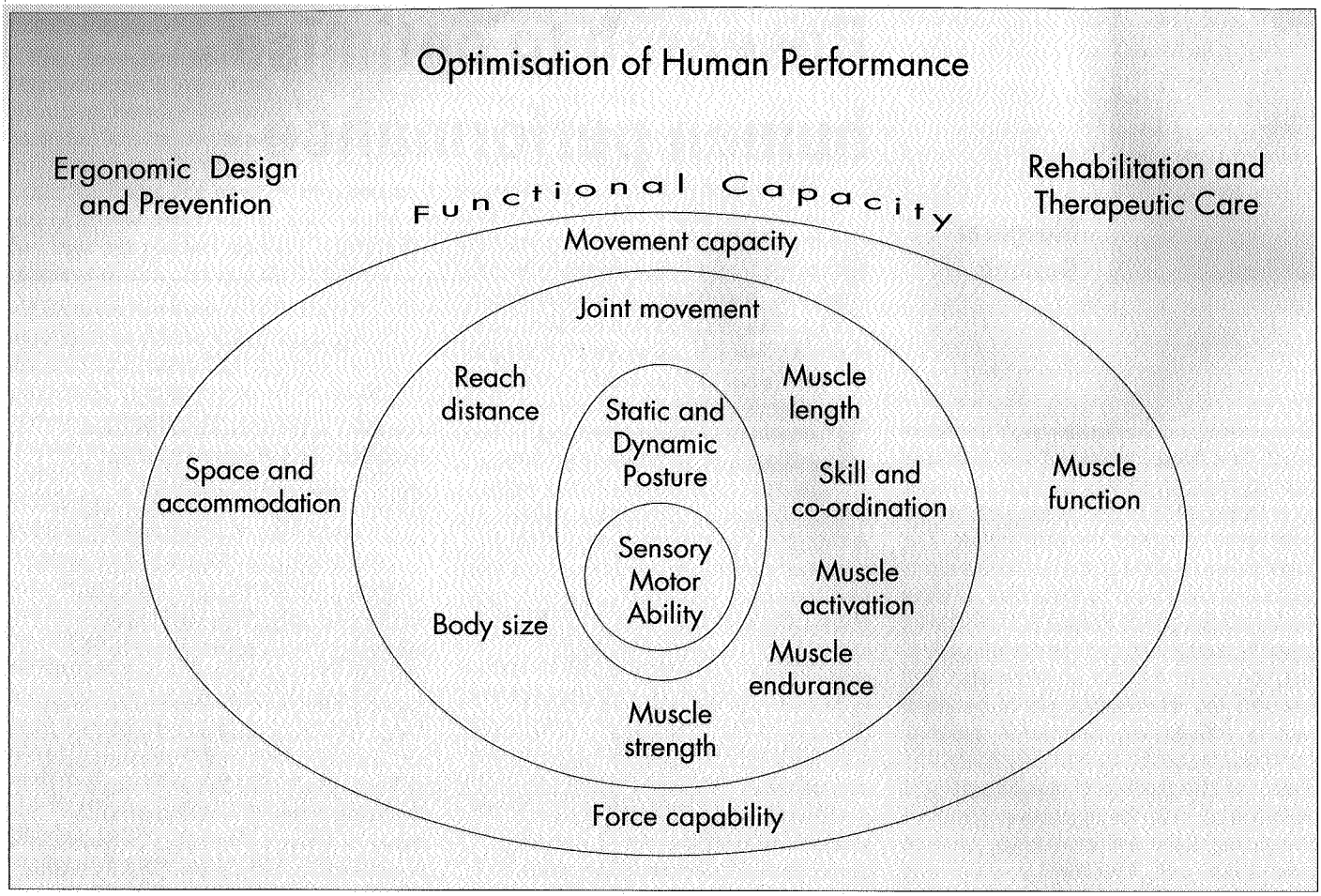

Figure 1.
Model of research addressing optimisation of human performance.
(Topic inter-relationships exist within and between circles).

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constraints of the basic structure and function of the human body (Bullock 1985). If the design of a workplace is not adapted to the natural patterns of motion, tolerance limits may be quickly exceeded. To ensure safety, the nature of individual differences in body size, strength and endurance must be appreciated when defining design specifications. Physiotherapists contribute to this consideration of man-machine relationships because of their ability to analyse body movements in detail, to evaluate postural abuse during dynamic situations, and to understand the clinical implications of misuse of the body (Bullock 1974a, 1990a).

Movement capacity: three dimensional motion analysis

Detailed analysis of dynamic posture demands measurement of body movements in three dimensions. Recognising this, the author undertook to develop such a process at a time when accurate three dimensional motion analysis was not considered possible. Video cameras and personal computers were not yet available and the design of a measurement process for analysis of complex motions was particularly challenging. After extensive trialling, stereoscopic photogrammetry (a technique used for aerial topographical mapping of stationary objects) was adapted for three dimensional motion analysis (Bullock 1974b, 1974c). Specified bony landmarks were marked with the newly available reflective tape and, using two phototheodolite cameras and synchronously firing electronic flash units, successive images of each taped spot were recorded on film during the subject's activity. The three space coordinates (X, Y, Z) of each image were determined on a stereo plotter, allowing calculation of magnitude and direction of motion of body segments. Evaluation of accuracy showed that measurements of small rapid movements had a standard error of only 0.6mm (Bullock and Harley 1972). It is gratifying to note that later developments in three dimensional motion analysis using video cameras

have incorporated a number of features of this pioneering procedure developed by the author.

Optimising pedal use: joint movement and control

Following surveys in industry and agriculture (Bullock 1973a), which revealed that more than 50 per cent of operators reported aching or fatigue in the lower back, research was instituted to improve the man-machine-task relationship during pedal operation. The study focused on determining the pedal orientation associated with minimal spinal movements. An experimental seat and pedal assembly was built with pedal and seat adjustability in all directions. The pedal could also be rotated to alter its angle with the horizontal or sagittal planes. For the experiment, the pedal was depressed over 135 travel paths using various combinations of these adjustments (Bullock 1974c, 1974d). The subject's body movements during pedal operation were measured by the stereo photogrammetric process described above. Three pointers, each bearing three pieces of reflective transfer tape, were fixed between C7 and T1, T12 and L1, and L5 and S1 and reflective tape was glued onto specified bony points of the pelvis and lower limb.

Movements in each plane for each joint, were calculated from data acquired. Analysis revealed that the optimal pedal orientation in terms of minimal spinal movements was with the pedal orientated at 45 degrees to the horizontal, continuous with the foot-on-the-pedal line and located anteriorly within a minimal leg reach and with minimal hip abduction or hip flexion. Information was also supplied about pedal alignments whose use would be detrimental to the operator (Bullock 1974c, 1974d and 1991).

Further observations of drivers of heavy machinery showed that vibration from travelling on uneven ground prevented the driver maintaining the foot pedal in the required semi-depressed position. A subsequent research study revealed a deterioration in ability of subjects to control the foot pedal in a number of semi-depressed positions while exposed to vibration of varying frequency and amplitude and thus highlighted the need for a design modification by engineers (Bullock 1990b).

Space and accommodation for optimum function

If equipment or work space is to be shared by individuals of varying sizes, it is essential that anthropometric measurements be collated for a representative sample of the using population. As clinicians, physiotherapists can also advise patients about methods of preventing further work-related postural problems (Bullock and Bullock-Saxton 1994). Research projects to overcome anthropometric limitations are essential (Bullock and Lanchester 1969, Bullock 1974e).

The likely limitations imposed by a firm torso restraint on pilots of light aircraft prompted the Department of Civil Aviation (DCA) to commission the author to carry out a study relevant to cockpit design. A preliminary survey of pilots revealed the nature of problems experienced and highlighted the need for design modifications (Bullock 1973b). Structural anthropometric data relevant to seating were then collected from representative samples of men and women civilian pilots of light aircraft, and a wide range of percentiles of each measurement were presented (Bullock 1973c, Bullock and Steinberg 1975). Results emphasised the importance of recognising individual differences in cockpit design.

Without inertia reels, the constraining effect of a lap and sash harness to functional arm reach within an aircraft cockpit or an automobile increases the difficulty of reaching controls. Recognising this, the reach capabilities of Australian men and women light aircraft pilots while restrained by firmly secured lap and sash harness were determined (Bullock 1974f). To define the space envelopes, arm reach was measured for both arms at 13 horizontal levels from above to below the seat at each of seven angles to the sagittal plane. Comparisons of the boundaries which could be reached by 95 per cent of male and 95 per cent of female pilots with the location of instrument panels and cockpit floors illustrated that, when wearing shoulder restraint, many pilots were unable to reach certain controls. Further study incorporating the newly available inertia reel showed that significant increases to reach boundaries occurred (Bullock 1974g). Subsequently, DCA required the installation of inertia reels in light aircraft cockpits. Further research at the request of the Commonwealth Department of Transport allowed application of relevant data to be made to functional arm reach within Australian automobiles (Bullock 1974h).

The collection of anthropometric data relevant to seating design is especially important for adolescents, in whom there is considerable variation in size for age, and for the disabled, whose individual needs are frequently overlooked. Because the period of secondary school education coincides closely with the rapid growth spurts characterising puberty, postural habits formed during this period can influence the skeletal and muscular systems, setting a pattern which could persist through life (Bullock (1987). Observations in schools revealed that problems of postural pain and fatigue existed, and anthropometric measurements taken of 130 students allowed recommendations to be made regarding room use, provision of colour coded chairs, supply of different sized and adjustable furniture and the need for postural education (Bullock 1990b).

Observations that, for some disabled persons, the wheelchair did not provide the anticipated level of support, control and mobility led to comparison of patient needs with wheelchair specifications (Nitz and Bullock 1983). On investigation, no patients examined with multiple sclerosis, spinal injury or muscular dystrophy displayed an erect, well supported posture in their wheelchair and many had an increased thoracic

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kyphosis and lumbar curvature and a scoliotic curve. Interference with arm movement from the backrest, limited access to wheels and difficulties in reaching and activating brakes were common. Pertinent anthropometric measurements and the relevant dimensions and adjustability of the wheelchair features were collected. Analyses highlighted the need for more suitable armrest heights, some adjustability of lumbar contouring of the backrest, at least two sizes in seat depth and an effective and easily applied lever mechanism for brake application. The importance of physiotherapists selecting a wheelchair with specifications matching patients' individual anthropometric dimensions was emphasised.

Force capabilities

A person's capacity to carry out a functional activity effectively at work, sport or at home depends to some extent on muscle strength and a limited capacity to apply an appropriate force could have serious implications. Of concern to the DCA during the 1970s was the relatively high incidence of fatalities in women parachutists and the number of these associated with failure to deploy the parachute. The DCA believed that design data were needed which would ensure that forces applied for testing of parachute ripcord release did not exceed human capacities. Accordingly, a study to specify the maximum pull force capabilities of women parachutists relevant to ripcord release was commissioned of the author.

A lightweight frame was fitted to the subject to allow force measurements for ripcord handle extraction from simulated pockets on each shoulder strap and for ripcord release on the main and reserve parachutes. Maximum effort in pulling on the parachute handle was measured using an electric resistance strain gauge. Results revealed that maximum forces were not large, the 95th percentile pull force capabilities ranging from 35 N for a 2.5 second pull to 71 N for a 0.25 second pull. Only 72 per cent of the female subjects could exert the 100 N pull force relevant for testing parachute pack opening devices at the time. In practice, forces required to release the ripcord pins could be influenced by many factors, any of which could increase the force required to release the pins, thereby creating a "hard pull". Results from this study were used by the DCA in consideration of standards applied in parachute testing (Bullock 1977 and 1978).

These projects highlight the fact that, in considering the relationship of a person to their workplace, an insight into the functioning of the human body and the physical limitations to movement, through research, allows physiotherapists to contribute to design aimed at improving safety, comfort and efficiency.

Movement capacity and therapeutic care

An understanding of normal limits of human performance is also important for therapeutic care. For example, examination of the total spinal motion or inter-segmental motion is routine for manipulative physiotherapists. To provide some normative data on which to make a comparison of motion in low back pain sufferers, 200 adult subjects aged between 15 and 65 years were studied (Jull and Bullock 1987a). The lumbar segments L5-S1 to T12-L1 were examined by manual methods for all physiological directions and postero-anterior glides, using a five point motion rating scale (Jull 1985). This study provided data for normal inter-segmental motion for each age group, for clinical reference. Results demonstrated an increasing incidence of hypomobility with age, a greater degree of hypomobility being revealed in rotation to the right and lateral flexion to the left than in other directions. The study revealed that segments L3-L4 and L4-L5 appeared to be most affected by structural changes which cause stiffness and limitation with age (Jull and Bullock 1987b).

Information about the normal active ranges of motion is also essential as a basis for diagnosis of abnormality. Lane's (1981) study of active spinal movements and passive intervertebral movement in 200 men and women aged between 15 and 65 years showed that, with increasing age, active range of motion decreased. The 40 to 50 year age span showed the most significant loss of active and passive motion. The ranges of motion of the female population were significantly greater than those of the male population in all movements, except for lumbar spine flexion, where males exhibited greater mobility in all age groups. The L4-L5 and L3-L4 intervertebral levels exhibited the greatest degree of hypermobility in all age groups in both genders and for the majority of passive movements examined.

Another anatomical area of considerable importance to the physiotherapist is the knee joint. It is the site of frequent injury to both soft tissues and skeletal structures, with a predisposition to complications and a resulting pronounced functional deficit. To provide information regarding the relative frequencies of the various forms of knee injuries receiving physiotherapy care, an incidence survey was conducted with the co-operation of all major hospitals and local private practitioners (Moore and Bullock 1977). The analysis revealed the high incidence of injuries from playing in all football codes and highlighted the frequency of medial ligament and medial meniscus lesions, patella fractures, bruises and tibial fractures. The influence of age, sport, season and occupation were also revealed.

It is not only in sport that the knee is injured. Concerned with the high incidence of knee injuries found in a survey of 250 ballet dancers in Australia and Europe (Wohlfahrt and Bullock 1982), a study was initiated to measure rotation occurring in hip, knee and ankle during the turn-out position assumed by dancers. Of particular importance, the study results revealed a high frequency of asymmetry in hip flexibility, which was correlated with an increase in lateral

rotation at the tibiofemoral joint and an associated increase in transverse mobility of the patella. The dangers inherent in forcing turn-out in ballet dancers must be acknowledged and both the ballet teacher and the physiotherapist must encourage the practice of careful technique and avoidance of faulty practice habits.

The influence of muscle function deficits on human performance

The balance of muscle forces about a joint forms the basis for dynamic activities, maintenance of stable joint position and good postural alignment. A change in function of even one muscle alters the balance between muscles, and can lead to incoordination of movement or pain. Changes in muscle function can be expressed in terms of alterations in muscle length, strength, endurance or activation, as illustrated in Figure 1. Knowledge of their influence on function and their inter-relationships is essential for improving human performance.

Muscle length and posture

Because a range of motion greater or less than optimal is likely to lead to musculoskeletal problems, measurement of muscle length is assessed by physiotherapists in determining causative factors for such problems as joint pain, postural deviations or muscle imbalance.

Evaluation of the limit of muscle length involves some subjectivity on the part of assessors and, for this reason, the level of repeatability of determination of end feel or the perception of motion of a body landmark should be known. This was evaluated by Bullock-Saxton and Bullock (1994) for muscles around the hip and pelvis, using standard positions and procedures (Janda 1994). Analysis indicated that muscle length measurement was repeatable, ie that the degree of variation was within 10 per cent. Those measures requiring determination of end feel of movement showed a high degree of repeatability. However, for those measurements requiring palpatory skills to detect onset of pelvic movement, the spread of measures was greater, suggesting that the therapist's palpatory skill slightly decreases the chance of repeatability. Tests carried out by different physiotherapists and a separate set of subjects determined a similar level of repeatability (Toppenberg and Bullock 1990). These studies have provided assurance that measurements of muscle length recorded by experienced physiotherapists should be repeatable and acceptable as a basis for progressive monitoring.

A diagnosis of muscle tightness requires knowledge of the range of normality. Collation of normative data is essential for reference by clinicians. The vulnerability of adolescents to muscle imbalances and to spinal pain and dysfunction, due in part to the unequal growth rate of soft tissues and bones, prompted a study to collect normative data for muscle length indices in muscles of the hip and pelvis in adolescents (Toppenberg and Bullock 1990). Applying tests described by Janda (1994), 103 female adolescents were studied, using an inclinometer and a Myrin goniometer to record the position where further movement was limited by stretch on muscle fibres and not by other limiting factors. Muscle length indices were then calculated (Cobb 1960). Tabulation of the true population measures and the 0.95 individual tolerance limits for each muscle length index offers data for clinical evaluation of normality.

A multiple correlation analysis investigated the relationships between muscle length indices measured. This revealed that shorter erector spinae and longer abdominal muscles occurred in combination with shorter iliopsoas and rectus femoris and longer gluteal muscles, a pattern proposed by Janda (1980) as occurring in the pelvic crossed syndrome.

To determine interrelationships of muscle lengths and posture, the degrees of thoracic kyphosis, lumbar lordosis and pelvic tilt were calculated in adolescent females by recording the angle of pelvic inclination and the inclinations of the spine L5-S1, T12-L1 and T1-T2, using an inclinometer (Toppenberg and Bullock 1986). Correlation of the degrees of kyphosis, lordosis and pelvic tilt with muscle length indices revealed that abdominal length was negatively correlated with thoracic kyphosis and positively correlated with lumbar lordosis. The former finding suggests the need to assess abdominals in cases of kyphosis. Both hamstring muscle length and erector spinae length were negatively correlated with lumbar lordosis. Claims by other authors (Kendall and Kendall 1949, Janda 1980) that hyper-lordosis is associated with back pain highlight the importance of routinely evaluating both the degree of lumbar spinal curvature and the relevant muscle lengths when assessing patients with back pain.

One group with a high incidence of back pain is women during pregnancy. Although muscle length testing around the pelvis is not practical during pregnancy, gradual lengthening of the abdominal musculature is a natural consequence of pregnancy and, combined with possible weakness of abdominal muscles and a change in the centre of gravity, compensatory postural changes are likely to occur. To determine any relationship between postural changes and the incidence of low back pain during pregnancy, 34 women were assessed at between 14 and 22 weeks gestation and at eight weekly intervals subsequently (Bullock, Jull and Bullock 1986). The degrees of thoracic kyphosis, lumbar lordosis and pelvic tilt were determined from measures of spinal and pelvic inclinations, using an inclinometer. Significant increases in curvature were found in the thoracic and lumbar regions during successive assessment intervals. However, no significant relationship between the incidence of back pain and posture in the thoracic, lumbar and pelvic areas during pregnancy was revealed.

The study supported the physiotherapy practice of strengthening those muscles concerned

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with flattening the lumbar spine and tilting the pelvis posteriorly. The finding that kyphosis increased as significantly as lordosis emphasised the importance of looking at a woman's total posture during assessment rather than focusing on the lumbar spine. Bullock-Saxton's (1991a) subsequent study demonstrated that the changed posture assumed at the end of pregnancy was maintained for up to three months after pregnancy. This implies that, with repeated pregnancies, spinal curvatures could change markedly. The interrelationships between muscle lengths and posture demonstrated by Toppenberg and Bullock (1986) suggest the need to monitor muscle lengths after pregnancy. This is an area worthy of further study.

The influence of injury on muscle function

The possible influence of injury on muscle function has considerable implications for patients and physiotherapists. A deficit in any aspect of sensory or muscle function could itself be a cause for injury or re-injury. Deficits in muscle endurance, strength or muscle activation associated with injury need to be identified to ensure appropriate prophylaxis and rehabilitation.

- **Endurance**

To determine whether local muscle injury leads to endurance loss, Somerville (1982) compared the levels of endurance in previously injured but now pain free hamstring muscles of 20 subjects and the non injured hamstrings of their opposite limb. Side-to-side differences were compared with those measured in matched, uninjured subjects. Endurance of hamstrings was measured using the percentage decline in torque over 50 repetitions of knee flexion at a speed of 180 degrees per second on the Cybex dynamometer. A significant difference between affected and non affected sides was found for previously injured subjects, but not for control subjects, suggesting that local muscle injury is associated with a decrease in local endurance. The results support the inclusion of endurance exercises in muscle rehabilitation after injury.

- **Strength**

Any loss of strength associated with injury has a potential influence on future performance and a knowledge of the pattern of strength deficit is important in prevention and rehabilitation. To contribute to this knowledge, the effect of a severe unilateral ligamentous ankle injury on the strength of hip flexors and extensors and knee flexors and extensors was studied by comparing strength between two groups of previously injured subjects (categorised according to side of injury) and matched uninjured control subjects (Bullock-Saxton and Bullock 1993). Isometric muscle strength was determined at outer, middle and inner ranges, using positions for antigravity muscle testing advocated by Kendall and McCreary (1983).

The study showed that a severe unilateral ankle sprain can be associated with a significant decrease in strength of muscles acting on the hip and knee joints. Compared with the control group, both experimental groups exhibited less muscle strength on both the injured and the uninjured sides, those with a left ankle sprain showing a greater degree of weakness. The study also revealed that the point in range and the side of injury were significant factors influencing weakness. Results highlighted the need for rehabilitation following ankle sprain, to monitor and to rehabilitate hip and knee muscle strength in all parts of range.

- **Muscle activation**

Janda (1983) claims that determination of the order of recruitment or activation of muscles performing a simple movement helps in understanding methods used by patients to move and that this helps to reveal the area of disability. To gain knowledge of the influence of injury on function of muscles remote from the injury site, the pattern of recruitment of muscles at hip and pelvis during hip extension was studied using subjects who had a previous severe unilateral ankle sprain. Electromyography (EMG) monitored muscle activation in each lumbar erector spinae, and the gluteus maximus and hamstring muscles of both limbs, while subjects performed a controlled hip extension movement from prone lying (Bullock-Saxton, Janda and Bullock 1994).

Using a process for quantitative EMG analysis developed by Bullock-Saxton (1993), temporal measures of the time span between onset of activation of each muscle and the commencement of hip movement, and the time span between onset of the first and last muscles to enter the hip extension activity were calculated. Comparison of results showed that for the previously injured group, the onset time of gluteus maximus was significantly delayed relative to hip movement and the time for gluteus maximus to reach maximum activation was also delayed, especially on the left side. A similar delay, though less marked, was found for the hamstring muscles.

These results highlight the possibility that changes in patterns of muscle activation after injury reflect a lack of contribution of individual muscles to initiation of movement and to group activity in a movement pattern. They also point to the need for research which would provide guidance in appropriate methods of restoring this aspect of muscle function. This research is currently under way.

It is possible that a decrease in proprioception associated with injury influences the changes in muscle activation through a decrease in facilitation of muscles. Such a deficit in proprioception associated with injury has been found by Bullock-Saxton (1992). Further, the existence of local sensory deficit following ankle injury, and its inter-relationship with remote muscle activation changes associated with injury, has been demonstrated (Bullock-Saxton 1991b and 1993). The question of whether subtle sensory deficits and delayed muscle activation exist prior to injury or are a result of injury is currently being investigated.

Rehabilitation and therapeutic care: optimisation of muscle function – sensory motor influences

Research which evaluates the effectiveness of different approaches to improving muscle function will help in the goal of optimising human performance, as reference to Figure 1 suggests. Several examples illustrate the research which is exploring this topic.

The quadriceps muscle is frequently injured and guidance for its effective rehabilitation is essential. To better understand quadriceps function, EMG activity of the vastus lateralis, vastus medialis and rectus femoris and lateral hamstrings during high speed knee extension and flexion was monitored (Richardson and Bullock 1986). In prone lying, the subjects extended the knee from 45 degrees flexion to 0 degrees against a light spring resistance and then returned to knee flexion. Three different speeds were applied and the study found that as speed of movement increased, highly significant increases occurred in activity of rectus femoris and hamstrings compared to the vasti.

These results suggest that high velocity, low load activity, particularly in the prone position, is inappropriate for improving quadriceps power, because muscle imbalances could occur due to specific facilitation of rectus femoris and hamstrings, with apparent inhibition of the vasti. Importantly, the study revealed that individual muscles of the knee respond differently when subjected to high speed alternating exercise movements in the prone position. In proposing a new approach to exercise, Richardson (1986) outlined clearly the need for a balanced programme which exercised both the mobilisers and the stabilisers to prevent the development of muscle imbalances and offered advice for the prevention of clinical conditions associated with sports medicine, such as patello femoral pain syndrome, shin splints and back pain.

The interrelationship of various aspects of muscle function are important clinically and need to be clarified. In this respect, clinical observation suggested that the influence of iliopsoas length on gluteus maximus function had implications for posture and certain musculoskeletal conditions. To investigate these length-activation inter-relationships, subjects with at least one tight iliopsoas were matched to a control group without tight iliopsoas and EMG was used to examine the magnitude of gluteus maximus activity and the sequence of onset of gluteus maximus muscle activation relative to the synergists during hip extension. EMG also monitored whether normalisation of iliopsoas length by stretching techniques caused an alteration in the motor patterns of erector spinae, upper and lower fibres of gluteus maximus and hamstrings (Souvlis 1985).

Results revealed that subjects with a tight iliopsoas exhibited less gluteus maximus activity before muscle stretching than after, particularly the upper fibres of gluteus maximus. The activity of the gluteus maximus of the experimental group closely resembled that of the control population after stretching, demonstrating the effectiveness of stretching shortened muscles when aiming to restore muscle balance around a joint.

In view of the established inter-relationship between sensory and muscle function (Bullock-Saxton 1991b and 1993), it seemed appropriate to investigate whether an increased sensory input, in the form of proprioceptive facilitation, would effect an earlier activation of gluteal muscles. Using previously injured subjects and a matched control group, EMG signals of gluteus maximus activation were recorded initially during hip extension from prone lying. Stimuli were then applied through small amplitude flexion-extension movements at the inner range of hip extension, while applying deep pressure to the gluteus maximus insertion. This stimulation was alternated with sweep tapping of gluteus maximus, and then the subject's maximal contraction of gluteus maximus while holding the leg in inner range hip extension. Sweep tapping is a brisk form of manual facilitatory stretch to underlying muscle and, after three such facilitations, EMG recordings were taken during each of three active hip extension movements. Results showed that following facilitation, gluteus maximus onset was significantly earlier for subjects with previous left sided injury compared with the control group (Bullock-Saxton 1992). Further studies are needed to determine the long term effect of local facilitation in altering the reflex inhibition of the gluteus maximus.

Considered to be potentially more effective in restoring muscle function in the long term was the general stimulation of the whole afferent system with the aim of improving sensory and motor integration. This possibility was investigated by using a sensory motor programme designed by Janda and Vavrova (1990) to enhance motor performance. For adults with no history of backache, musculoskeletal injury or postural defects, facilitation was offered for one week through regular use of "balance shoes" during walking. EMG recordings of walking barefoot and with balance shoes before and after facilitation provided data for evaluation (Bullock-Saxton, Janda and Bullock 1993). Results demonstrated that this form of general facilitation increased activity of the gluteus maximus at a statistically significant level. The increase in muscle activity by 209 per cent effected by use of balance shoes at the first trial demonstrated the immediacy of the body's response to sensory stimulation. Further, the continued use of the balance shoes so facilitated the gluteus maximus that, after one week of facilitation, the muscle was more effectively activated with barefoot walking, rendering the difference in activation between barefoot walking and balance shoe walking non significant. Extension of this research to subjects with clinical deficits is now in progress.

The continued study of muscle function and of factors influencing

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muscle balance is considered to be one of the most important areas for physiotherapy research, as the consequences of muscle imbalance include many of the signs and symptoms addressed by physiotherapists in their management of patients with musculo-skeletal disorders. It is hoped that through further research in these areas, advice can be given which will enhance physiotherapy treatment and optimise human performance.

Therapeutic modalities

Attention to muscle imbalance is not the only area for emphasis by the physiotherapist in restoring muscle activity and motor performance. Various therapeutic approaches are important for relief of pain or the encouragement of muscle contraction. Reviewing the development in knowledge of the effect of ultrasound on healing, the need for controlled clinical trials in physiotherapeutic practice was highlighted (Fyfe and Bullock 1985). The problem confronting workers with therapeutic ultrasound of ensuring the reliable calibration of output, either for clinical use or for research purposes, was revealed through Fyfe's (1985) extensive studies on the effect of ultrasound on induced inflammation. Factors capable of affecting treatment of patients with ultrasound were identified and the importance of applying the pressure of informed opinion for better testing facilities emphasised (Fyfe and Bullock 1986).

The influence of developmental sensory motor deficits on human performance

Interference with movement is not only acquired through external influences. It can also exist as a result of disturbances in the normal developmental process. Normal development of movement involves the maturation of sensory and motor processes and sensory motor deficits can be a limiting factor to function.

During the early 1970s, considerable attention was focused on problems presented by children diagnosed as having Minimal Cerebral Dysfunction (MCD), a term used at the time to refer to children functioning within the normal intellectual range, but exhibiting mild clinical neurological symptoms (Bullock and Watter 1978). The term minimal cerebral dysfunction has been replaced now by Motor Coordination Difficulties (MCD).

Recognition of the need for research relating to physiotherapy management of these children led to the author's establishment of a research clinic devoted to exploring some of the changes in human performance associated with developmental limitations in sensory motor capacities, and determining the effectiveness of physiotherapy approaches in overcoming those developmental deficits. It has been gratifying to see the advances in knowledge which have emanated from this facility.

Sensory motor deficits in children

To gain a better understanding of risk factors in family and medical history which might contribute to sensory motor deficits in children with MCD, a questionnaire study of 1,020 MCD children was carried out. Comparison with general population data showed a set of interesting differences (Bullock and Watter 1987). These included the developmental outcome of twins, the early background of adopted children, the influence of certain prenatal and perinatal factors on development, and the effects of middle ear infections. In addition, the reported frequency of children with MCD in remedial education classes suggested the need to look closely at those referred to Guidance Officers for educational or behavioural problems, to identify any neurological deficits which might be associated with other difficulties.

Initial observations revealed the absence or decrease in post-rotatory nystagmus in some children with MCD. As nystagmus is commonly assessed in children with neurological problems, its validity in testing MCD children was evaluated. Using a rotating chair to provide acceleration and deceleration stimuli, post-rotatory nystagmus was compared between MCD hyperactive children with associated spatial awareness problems and a matched group of normally active children, using electronystagmography (ENG) (Harrison and Bullock 1978). Results showed that MCD hyperactive children had a reduced duration of post-rotatory nystagmus when not able to visually fixate. Nevertheless, results from the control group demonstrated that a test of nystagmus duration alone was insufficient to discriminate between a hyperactive and a normally active child. The results also stressed the importance of considering individual responses in conjunction with other neurological symptoms.

- **Oculo-motor deficits and reading skill**

The likelihood that children with MCD could have reading difficulties associated with ocular motor ability led to two supervised studies in this area. Children with MCD often show an inability to move the eyes smoothly and regularly in following a moving object. To study this, comparisons of the smoothness of eye-follow were made between MCD children and a matched control group of normal children. ENG recorded eye movements while the child followed a light moving at a controlled speed. Analyses revealed that the MCD children had a significantly higher level of abnormality in eye-follow than normal children (Ovens 1977).

To study the possible contribution of oculo-motor problems to reading difficulties in MCD children, Hewitt (1979) compared children of normal intelligence and receiving remedial reading teaching with a matched control group (not receiving remedial education). Neurological testing identified two sub-groups of children with reading problems: those with associated MCD (42 per cent) and those without MCD (58 per cent). Relevant features of eye movements such as right-to-left-scan-back, eye-follow quality and stereoscopic vision

were examined during the process of reading, using ENG. Results revealed that MCD children had poorer quality eye movements (in number and direction) than the normal control group and that the MCD group showed the greatest variance in scores. MCD children with reading problems were shown to have a lower quality of eye-follow than children with reading difficulties but no neurological impairment. The latter group was found to have significantly worse eye-follow than the normal control group. Consistent with Bullock and Watter's (1978) findings, not all children with MCD showed oculo-motor problems. Nevertheless, the likely interference with educational progress makes this a field for closer study.

- **Hand function and writing skill**

The ability to write clearly and with ease is fundamental to good progress at school and a clearer knowledge of features associated with development of poor writing skills could help in their prevention or early resolution. To establish whether hand function differed between MCD and normal children, sensory awareness and the quality of fine motor skill performance in children with MCD and a matched control group were examined (Kelly 1983). This study showed that MCD children displayed poorer perception of tactile and proprioceptive stimulation in the hands, a slower rate of fine motor skill performance and a greater incidence of excessive effort, associated movement and postural instability than their normal counterparts.

A later study explored relationships between sensory motor deficits in MCD children and their writing problems (Watter and Bullock 1989a). A comparison of deficits in 372 MCD children referred because of writing problems with a control group of MCD children without writing problems identified the specific nature of their sensory motor problems. For example, 70 per cent of the children had deficits relating to proprioception in the arm and 77 per cent to proprioception in the hand, while deficits in tactile function in the hand (35 per cent) were greater than in the body (18 per cent). The occurrence of hand-related deficits in the writing problem MCD group was greater than in the control MCD group. An increased incidence of factors such as postural instability, excessive effort and associated movements found in the MCD children could have deleterious effects upon their quality of fine motor performance and further study of this important area of skill performance in MCD children is warranted.

Sensory motor development in intellectually handicapped children

To explore the sensory motor capacities of intellectually handicapped children, a study was undertaken to determine whether the sensory motor capacities of mentally retarded children were more closely related to chronological or mental age and whether there were any common deficiencies in the sensory motor capacities of children with retarded intellectual development. Children with a chronological age of 10 years and a mental age of five years were compared with two groups of children with normal intelligence, one group aged 10 years and the other group aged five years (Chenoweth and Bullock 1978). Results of a comprehensive neuro-developmental assessment suggested that the sensory motor capacities of an intellectually handicapped child were correlated more to mental than to physical development. Their basic problems included tonal abnormalities and poor awareness of body positioning, as manifested in poor balance (dynamic and static) and in poor coordination (gross and fine). A high incidence of poor vestibular functioning compounded their balance problems. Results suggested that physiotherapy management needed to focus on providing sensory input to encourage correct precise motor responses. Some suggestions for physiotherapy management arising from this study have been offered (Chenoweth et al 1978).

Sensory and motor development of preterm infants

Recognising the need for detailed knowledge about preterm infants, Burns (1978) studied the neurological, sensory, motor and general developmental progress of 135 infants born more than five weeks before term. Over a period of 12 months, 122 infants had progressive post term evaluations, using a standardised infant ability scale and a graded neuro-sensory and motor assessment. Although the abilities of the age adjusted preterm infants compared favourably with the standardised scale of expected age normal abilities, there was some persistence in primitive motor reflexes and an apparent delay in development of postural reactions. Six per cent of the group had definite neurological handicaps (Burns and Bullock 1980). Of this initial group, 82 per cent were assessed regularly through their pre-school years (Burns 1984). Results indicated that a normal sequence of development was followed by the majority of children. Although the incidence of cerebral palsy, speech difficulties and minor motor co-ordination difficulties was higher than average, all but two children were ready to enter school with their peers (Burns et al 1984). At the adjusted age of five years, the development of 106 of the children was compared with the development of 103 children born at term and matched for gender, year of birth, birthplace, race and residential location (Burns and Bullock 1985). Factors distinguishing the preterm children from their full term peers included small involuntary hand movements, less competent gross motor ability, poorer verbal performance and more variability in behaviour, postural response and balance. These studies emphasised the need for regular comprehensive developmental assessment of preterm infants for identification of related age related problems.

To examine whether a physiotherapy programme based on sensory stimulation designed specifically to encourage active contraction of

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developing muscle would be of value to the preterm born infant, Cole (1988) studied 95 very preterm, very low birth weight infants who showed no evidence of abnormal development. After selection of a suitable sensory motor stimulation programme and of reliable and valid measures of motor performance, a longitudinal study of motor development while offering three different approaches to intervention, was initiated. Results demonstrated that motor performance in preterm born infants without disabilities likely to restrict movement can be enhanced by 12 months of adjusted age, with a physiotherapy programme which stimulates appropriate muscle activity. Improvement appeared to be related to the duration of offering the stimulation and results suggested that motor development in this group of infants could be enhanced by a domiciliary programme of physiotherapy following discharge from hospital.

Preventive and therapeutic care: optimisation of sensory motor function

- **Effectiveness of physiotherapy intervention**

Of fundamental importance for physiotherapists is a knowledge of whether the sensory integrative approach to management of MCD is effective in resolving identified developmental deficits. A study to determine this was conducted, in which children in experimental and control groups were assessed using a neuro-developmental assessment outlined for MCD children by Watter and Bullock (1975). A rating scale was devised to record degrees of abnormality (Bullock and Watter 1977). For the experimental group, a home treatment programme focused on the child's most basic level of problem and, with improvement, was modified to involve higher levels of functioning. Children were reassessed after three and six months.

The experimental group showed a decrease of 86 per cent (school age) and 75 per cent (pre-school age) in total abnormalities exhibited after six months of treatment. These results suggested that, after an additional period, return to normality would occur for the majority of children. On the other hand, the untreated groups of children of similar age showed an increase of 7 per cent and 14 per cent respectively. The significant differences revealed on analysis demonstrated the effectiveness of physiotherapy in resolving sensory motor deficits (Bullock and Watter 1978).

- **Long term effectiveness**

A separate study was undertaken to ascertain whether any changes in function effected during six months of treatment were maintained for a further six months (Watter and Bullock 1987a). Two matched groups of children with MCD were assessed neurologically. One group received physiotherapy management appropriate to individual needs for six months, but the other did not. All children were reassessed after six months, after which no further treatment was offered to the experimental group, and again after a total of 12 months.

Initially, the experimental group exhibited an abnormality rating of 42 per cent and the control group 39 per cent. After six months, experimental group abnormalities had decreased to 6 per cent (Watter and Bullock 1987b), confirming the results of Bullock and Watter's (1978) previous study of intervention effectiveness. This low level of abnormality remained constant for six months of non-intervention. In contrast, after six months, the mean percentage of abnormalities in the control group rose to 42 per cent, a figure which did not improve after a further six months. This study provided substantial evidence that sufficient improvement in neurological functioning could be gained from six months of physiotherapy treatment, for children to retain that level of sensory motor functioning post-treatment.

- **School based programmes**

A further study showed that for children with only minor degrees of difficulty in motor co-ordination, but for whom this results in functional problems, a physiotherapy directed school based group programme offered under guidance by remedial education teachers can be an effective means of resolving problems (Watter and Bullock 1989b).

- **Effectiveness of physiotherapy for adults with MCD**

Clinical evidence suggested that some adults could benefit from neurological assessment and a sensory integrated approach to treatment. To investigate this, a group of 34 adults with long standing presenting signs of MCD were assessed (Watter and Bullock 1989c). Problems were found in writing or hand function (61.8 per cent), reading (41.2 per cent), spelling and memory (29.4 per cent) and gross motor coordination (29.4 per cent). Deficits in writing skills, such as illegibility, slowness of writing and discomfort or rapid fatigue during writing tasks occurred most frequently. Treatment reflected sensory motor deficits and used activities suitable for lifestyle and age, and at monthly review, programmes were updated.

After only two months, the problems of 50 per cent of the subjects had been resolved and, after five months, 91 per cent required no further treatment. It is interesting to note that the areas of sensory motor deficits found in adults were essential skills and, where not resolved in childhood, could contribute significantly to learning difficulties and a sense of frustration and loss of self esteem in adults. This study identified a need for closer investigation of adults with problems associated with MCD and highlighted the importance of developing more refined assessment and treatment strategies appropriate to age.

- **Effectiveness of physiotherapy on associated behaviour problems**

Noting that many children with MCD seemed to have associated behaviour problems, the effect of neuro-sensory motor therapy on presenting behaviour problems in MCD children was evaluated in a supervised study (McMahon 1980). Children with

MCD and associated behaviour problems were randomly allocated to experimental or control groups. A Quay Paterson Behaviour Checklist evaluated behaviour problems and a Piers Harris Self Concept test was administered before and after intervention. Treatment for the experimental group was individualised according to presenting problems, while children in the control group received a modified relaxation programme. All children were re-assessed after three months. Results supported the notion that there is a primary relationship between the neuro-sensory dysfunction of MCD children and the co-existent conduct disorders reported, and that a programme which improves their neuro-sensory motor functioning has a direct effect on their presenting behaviour problems. While further research is needed in this area, the evidence of carry over of improved neuro-sensory motor function to associated life problems through appropriate physiotherapy intervention is encouraging.

- **Effectiveness of physiotherapy on associated specific learning disabilities**

In Bullock and Watter's (1978) study of MCD children, 58 per cent of school aged MCD children were found to be experiencing learning difficulties and it was hypothesised that use of developmental physiotherapy for children with both MCD and learning problems would improve both areas (Watter 1983). A controlled study was conducted to test this. Of 204 children attending remedial education classes, 62 exhibiting signs of MCD were randomly assigned to one of two matched groups (1 and 2). All children in Group 1 received six months of physiotherapy, while Group 2 received no physiotherapy. Neurological assessment revealed no significant differences in initial scores between the two MCD groups. A second control group of children who did not have MCD was created by random selection from suitably aged children in remedial education classes. Children with MCD were reassessed after six and 12 months and, in addition, MCD Group 1 was assessed after three months of treatment.

The educational progress of all children was evaluated using standardised tests (eg the Milton word recognition test) and a variety of routine classroom teacher assessments. A scored level of performance for before and after the period of physiotherapy intervention in mathematics and English was available to chart the child's progress, as well as some information for social studies and science. Eight children in each of the three groups were assessed by a School Guidance Officer who applied standardised tests. While the wide variability in changes occurring over time suggested the influence of complicating factors other than MCD, results provided some evidence that physiotherapy management programmes for children with MCD and associated learning difficulties do contribute to an improvement in educational progress (Watter and Bullock 1983).

The broad implications of deficits in development of sensory motor function for human performance highlight the need for continued research in this area. The studies carried out to date provide strong support for physiotherapy intervention at an early age to prevent the development of sensory motor deficits, and demonstrate that appropriate management can be offered even in adulthood to ameliorate deficits and to optimise human function.

Conclusions

Important to physiotherapy practice is an understanding of the inter-relationships between the many features influencing human functional capacity. The research reported in this paper has explored some of these features and has demonstrated the importance of considering both prevention and therapeutic care in efforts to optimise performance. Collation of normal data for muscle length measures, joint and body motion and anthropometric dimensions for body size, reach distances and force application has provided information useful for clinical decision making and ergonomic design. Studies of the effect of injury on aspects of muscle function and movement capacity have not only revealed the inter-relationships between sensory and motor function, but have also provided preliminary evidence of the value of a sensory motor approach to physiotherapy intervention. The importance of exploring the nature and effect of sensory motor development and the value of offering specific physiotherapy intervention programmes has been highlighted in studies of preterm infants, and of children and adults with developmental sensory motor deficits.

Optimisation of human performance is one of the primary aims of the physiotherapist and much remains to be learned. The research reported here demonstrates some of the progress towards achieving this goal.

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